THE REBUILDING AND REPAIRING OF ELECTRIC MOTORS AND GENERATORS.

A THESIS SUBMITTED TO THE FACULTY OF THE SCHOOL

OF ENGINEERING OF THE UNIVERSITY OF KANSAS.

FOR

THE DEGREE OF ELECTRICAL ENGINEER.

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PREFACE

In the repairing and rebuilding of electric motors and generators there are three principal factors which must be considered. These factors are, service, cost and reliability. If a machine can easily be spared from the place in which it is in use then the factor of service disappears. The factors cost and reliability are almost always present though there are a few owners to whom the cost of a job is always secondary to the securing of reliable performance. The factor of reliability is always present. A machine when repaired must give satisfactory performance. Very few electrical machines are on the market today that are defective in design to the extent that they cannot, with reasonable care, be made to give reliable performance. When such machines are discovered no attempt should be made to repair them unless definite understanding is had with the owner that reliability is not promised.

There are many cases in which service is the main factor. Ventilating motors in mines, motors on power machinery in machine shops, and elevator motors in practically every location are examples of instances in which service is paramount to cost. Service must be maintained in such places at any cost. The delay of a few days might, and often does, entail an enormous cost so that the owners of such equipment are glad to pay the overtime charges demanded by all Union men and most Non Union men for overtime work rather than have the machines out of service for a longer time.

The factor of cost is a very important one, however, and often the ability of the repair man to secure a valuable contract depends on the price at which he can do the work. The cost of repairing a machine, except in instances where service takes precedence, must bear a reasonable ratio to the cost of new equipment.

The object of this thesis is to describe the repairing of three typical machines which have come under the author's personal supervision and observation during the past two years. Special reference will be paid to the three factors, service, cost and reliability.

THE REBUILDING AND REPAIRING OF ELECTRIC MOTORS AND GENERATORS AS TYPIFIED BY THREE SPECIFIC INSTANCES.

The first machine the repairing of which will be described was a thirty-five horse power, two hundred and twenty volt, three phase, sixty cycle, nine hundred revolutions per minute, squirrel cage, induction motor manufactured by Fairbanks Morse & Co.

In this type of motor the rotor has cast bronze short circuiting rings. In assembling this rotor the bars are put in place in the slots, the rotor placed on end with the ends of the bars projecting into a mould of the proper shape and melted bronze poured in the mould around the bars. It is the contention of the manufacturers that the bars are fused into the ring in such a way as to make a perfect electrical contact.

This motor had operated for five years with no trouble of any kind. It then began to show great difficulty in coming up to speed causing heating of the rotor. This condition became worse until, when the owner called in outside assistance some of the bars of the rotor had been almost red hot. The indications were that the rotor had too high resistance, however, the fact that the short circuiting rings were cast to the bars seemed to preclude any such possibility.

In many forms of squirrel cage induction motors the short circuiting rings are soldered to the bars, in others they are riveted, and soldered, in still others they are bolted and soldered. In a motor of any of these types it is quite a common occurance for the rotor to develop a high resistance through over heating of the rotor and the throwing of its solder. This is usually caused by an over-load or low voltage.

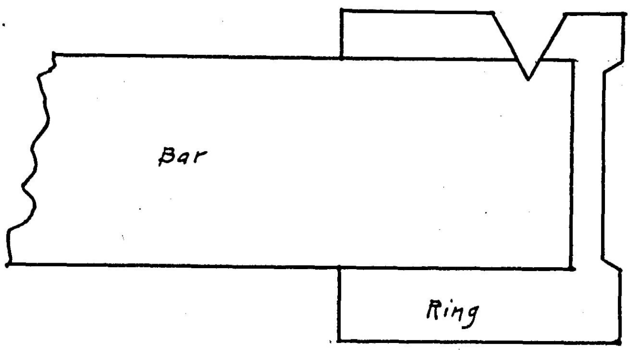


Figure #1.

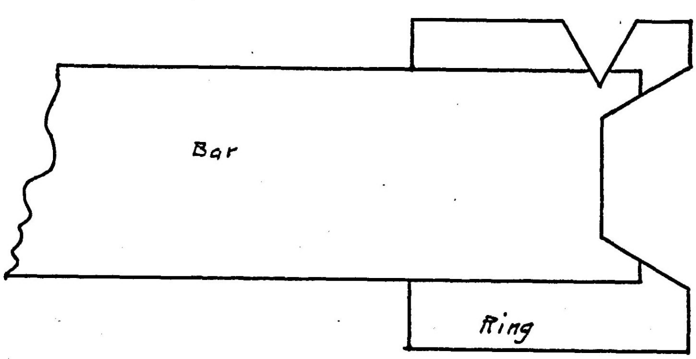


Figure #2.

However, in this case though every indication was of a high resistance rotor the cast short circuiting rings made it rather difficult to determine that such was actually the case.

The rotor was removed from the motor, mounted in a lathe, and a channel cut in the short circuiting rings (See Figure #1). The operation was watched very closely and when the cut had reached the end of the bars a layer of black substance resembling carbon was found to have coated the bars where they were supposed to be thoroughly fused to the bronze ring. The coating was thickest on the bars in which the discoloration of the copper showed the most heat had been developed. A few of the bars had heated very little and on these the coating was found to be very light.

The cut was continued to a depth that assured a surface of contact equal to the cross sectional area of the bar. (See Figure 2). The ring was of varying thickness and the ends of the bars were not in line so that in order to secure a good contact surface on all the bars it was necessary to cut very deep into some of them and to cut entirely through the ring on the side where it was thinnest. After a channel had been cut in each ring the rotor was removed from the lathe and stood on end. Fire clay was built up around the ring and the channel in the ring thoroughly brazed with a welding flame of oxygen and acetyline gas. After this the channel was welded full of Tobin bronze.

The rotor was again placed in the lathe and the ends of the rings faced off smooth. The job looked good and it was thought that the trouble had been corrected. On placing the rotor back in the motor, however, the motor not only failed to start its load, which by the way was a very heavy one, but blew the twenty-five ampere fuses on the twenty-two hundred volt primary which fed the transformers on this installation. The decision was soon reached that the rotor now had too low resistance. It was again removed and mounted in a lathe and a cut of about one-sixteenth of an inch taken from each end ring. When it had been re-placed in the motor the results of a test showed that the decision in regard to the resistance was justified. After two more cuts had been taken from each ring the motor was able to start its load without taking too heavy a rush of current and has since then operated in a very satisfactory manner.

The conclusions drawn in regard to the somewhat peculiar performance of this motor are as follows: The contacts between the bars and the short circuiting rings never were perfect. While the bars were new and clean, however, the contacts were good enough to allow enough current to flow to bring the rotor up to speed. As the motor became older dirt and oil from the bearings worked their way back around the bars into the ring and the resistance was very considerably increased. Since a rotor with a high resistance will start a greater load on less current than one with a squirrel cage winding this motor would still start without blowing fuses. However, the high resistance did not allow sufficent current to flow to bring the motor up to speed. This induced heavy currents in the rotor causing heating. This condition became worse until the owner noticed smoke coming from the motor and the author was called in to investigate the trouble.

The cost to the customer was about two-thirds the cost of a new rotor. There was very little delay in completing the job, about three days being required from the time the work was started till the motor was operating again in a satisfactory manner. Since service was the principal thing desired by the owner and since incidentally the cost of making the repairs was reasonable the job must be considered a success.

The second piece of work to be described is the complete rebuilding of a one hundred horse power, three phase, thirty cycle, four hundred volt, five hundred and eighty revolutions at full load, Westinghouse motor. This motor had been through a fire in a Cripple Creek mine. The insulation had been burned from the coils except in the slots where mica had been used. The solder was melted from the rotor and the babbitt from the bearings. Water had been turned on it when it was very hot cracking the end housings. There had been several bad electrical burns due to grounding of the coils in the stator which had fused large sections of the laminations together.

The coils were wound with two turns of copper strap thirteen-hundredths of an inch thick by four-tenths of an inch wide. There were one hundred and eight slots, the coils being spaced in slots one and nineteen. There were six coils per pole per phase and the whole machine was connected in single star.

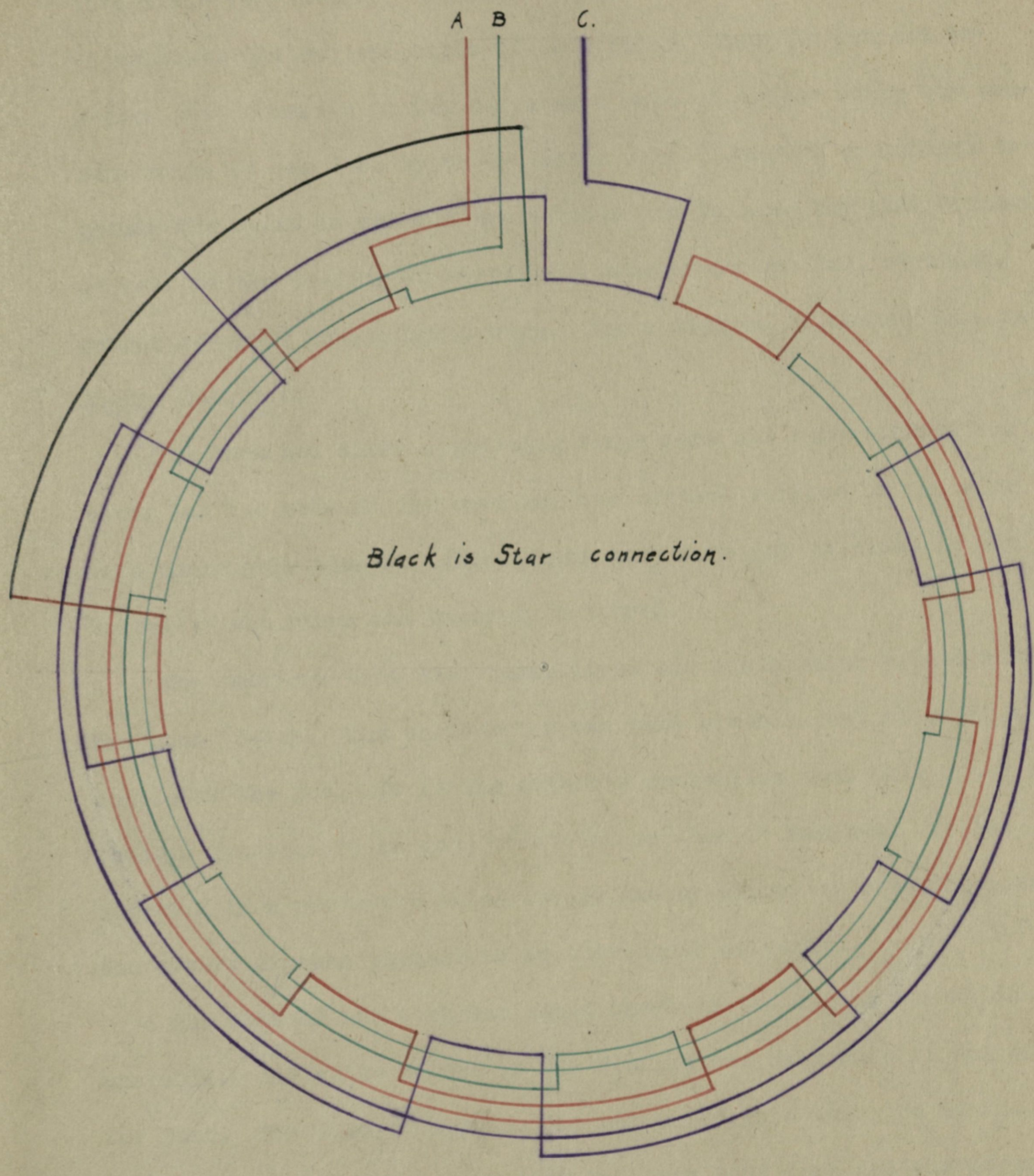
The coils were removed from the machine, thoroughly cleaned with steel brushes, and the terminals of each coil carefully tinned. They were then painted with a good grade of air drying insulator. After the insulator was thoroughly dry each turn of each coil was taped with a lapped layer of cotton webbing. Another coat of air drying insulator was then applied and allowed to dry after which the two turns of each coil were brought together and the portion lying in the slots taped with varnished bias cambric. Then each coil was taped over with a lapped layer of cotton webbing. After another coat of air drying insulator had been applied and baked on, the coils were ready to be put back in the stator.

The laminations were then removed from the stator and all the burned spots trimmed out. Each separate lamination received careful attention. It is the author's experience that a few slightly bent laminations will cause considerable difficulty in getting such machines back together. In re-placing the laminations care was given to have no two places from which portions of the teeth had been cut come together. By using this method no burned spots were apparent when the lamination had all been put in place.

In spite of all the care that was used in straightning the laminations and putting them back in place some difficulty was experienced in re-placing them all back in the stator. A rigging of rails of a weight commonly used for mine tracking was built up around the stator held in place by bolts screwed into the housing bolt holes. From under these rails small improvised jack screws were used (See Figure 3) on all sides of the stator at the same time forcing the laminations down in place. A little filing with a sixteen inch mill file was all that was needed to make the sides of the slots smooth. When the laminations had been secured in place by inserting the ring and key provided for that purpose and given a coat of air drying insulator the stator was ready to receive the coils.

A slot insulation of one thickness of cement paper and one thickness of varnished cambric was used. Slot strips of hard maple were used to block the coils in the slots.

In putting the coils in the slots great care was used to avoid bruising the insulation. Rawhide hammers and fiber tools were used and no metal bars or wedges were allowed on the job. The coils went



Connection diagram of 100 H.P. A.C. motor.

Figure #4.

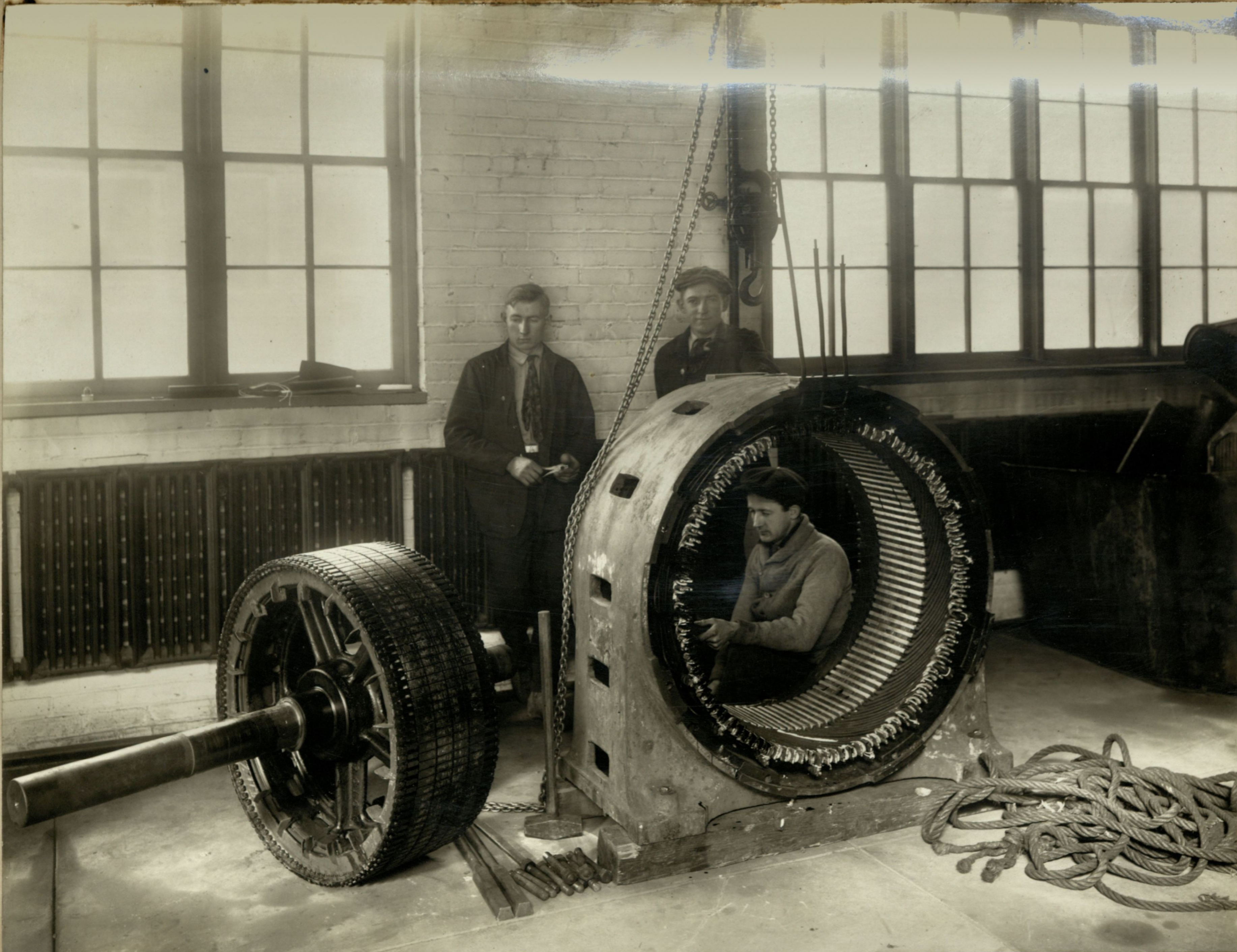
into place very snugly. Phase insulation of treated canvass was used to separate the two end coils of each phase. Lugs to connect together the terminals of the coils were made of copper strip six one-hundredths by one inch by three inches long. Jumpers to connect together the coils in the different poles and to make the star connection as well as the leading in wires were made of number two, stranded, rubber covered, double braid wire. For a diagram of connections see Figure Number 4.

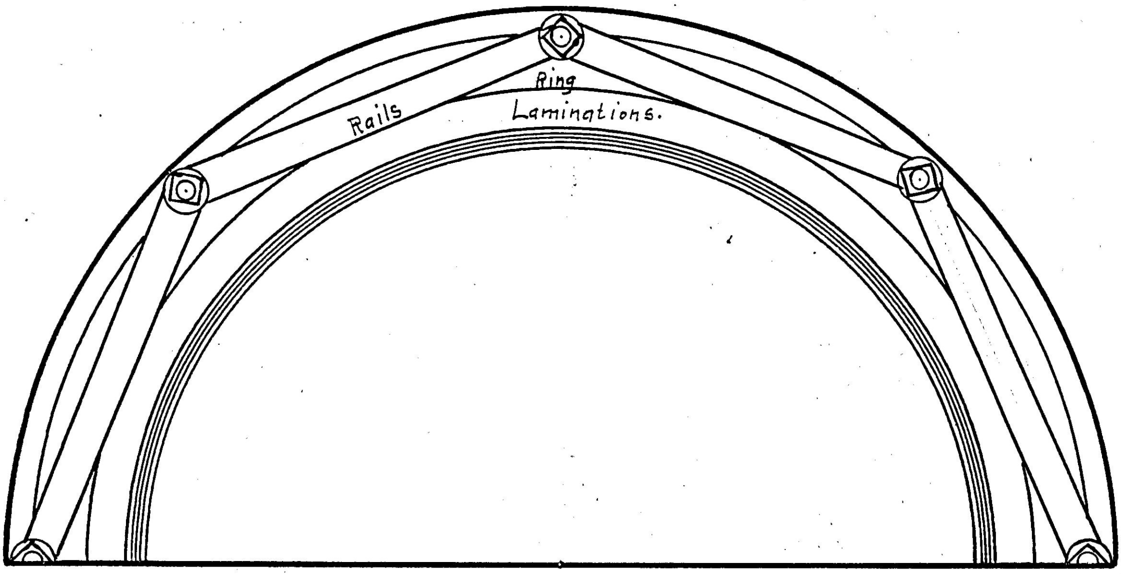
The bars and short circuiting rings were all removed from the rotor and the ends of the bars and the contact surface of the ring were thoroughly tinned. After which they were put in place in the rotor bolted to the rings and securely soldered.

The bearings were then rehabbitted and one housing welded where it had been broken. The whole motor was then given a coat of paint which completed the job. It is the author's contention that this motor was then in practically as good condition as when it was new. It has operated in a perfectly satisfactory manner since its rebuilding and the owners express themselves as thoroughly satisfied.

The cost of the work was about one-half the amount for which it was sold. Its value before it was rebuilt was only what it was worth for junk. The item of service did not enter into this job as the mine in which it had been in operation had been shut down and the object of the owners in having it repaired was to put it in condition to sell.

Figure Number 5 is a photograph of this motor just after the coils had been put back in place and re-connected.





Shaded portion indicates slots.

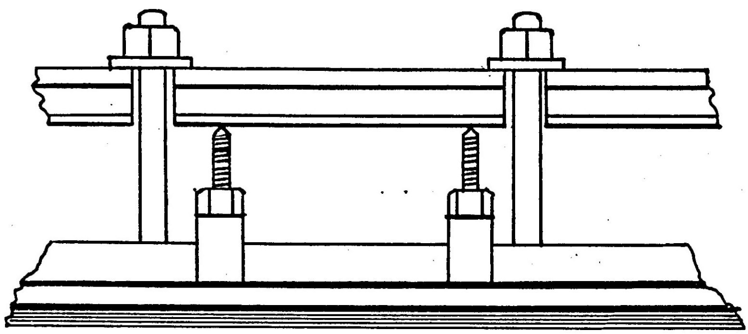


Figure 3.

The third piece of work to be described in this thesis is the rebuilding of the stator of a fifteen hundred kilo volt ampere, sixty-six hundred volt, sixty cycle, three phase, eighteen hundred revolutions per minute, turbine generator made by the Allis-ChalmersCo.

This machine had always been extremely sensitive to lightning. Many unsuccessful attempts had been made to correct the trouble. There was a set of electrolytic lightning arresters and a set of horn gap arresters on the line where the feeders enter the building. From the switch board the feeders run to the generator in lead encased cable drawn in iron conduit which of itself is a very good protection against lightning. Just beneath the machine a set of horn gap arresters with as small a gap as the voltage of the machine would allow had been put in, yet with all this protection the slightest surge of lightning would puncture the insulation of the coils in the stator and burn a ground to the laminations. The machine would then hold the arc which the lightning had started and in a very short time considerable damage was done.

This had happened several times. New and better insulated coils had been put in with no apparent permanent advantage.

This machine is in use in a very mountainous country where frequent and severe electrical storms are common. At timesthe operator has very little warning of an approaching storm and the consequence was that the machine was almost always in trouble during the summer season. It happens that it is at this season that it is most in use and its continual burning out with the delay and expense attached was very annoying to its owners.

The last time the lightning came into it the operator in charge became so excited that he neglected to kill the machine as soon as it was hit. The arc started by the lightning was continued by the generator until a large hole was burned in the laminations as well as the insulation burned from about half of the coils. Since there had been several burns in this machine each one grounding to some portion, usually in the lower half of the stator, it was thought advisable to remove both the coils and the laminations and make a thorough job of re-insulating the coils and re-placing the laminations.

The laminations were all removed, trimmed and straightened as described in the portion of this article dealing with the repairing of the one hundred horse power Westinghouse motor. In re-placing them a layer of paper was inserted between each tenth layer as an insulation against hysteresis. Great care was used in securing perfect alignment of the laminations as it had been observed that a projecting lamination which cut only a very slight way into the insulation had always been the point at which the machine grounded on a transformer test. From this it was supposed that it was at such a place that the lightning breakdowns occurred.

The greatest care was exercised in re-insulating the coils. Each conductor of each coil was separately taped with cotton webbing and varnished bias cambric. Air drying insulator was used to impregnate the coils and the whole coil after each conductor had been properly insulated was taped carefully with varnished bias cambric and cotton webbing. A final layer of a heavy cotton webbing was used and the whole coil was then given a coat of aluminum bronze. The idea in using the aluminum being that this coating would give a sort of capacity effect tending to allow a brush discharge of whatever static might be in the machine instead of causing a lead spark with the subsequent rupture of the insulation.

The slot insulation was made of fiber. It is the author's experience that mica is a poor form of insulation where square conductors are used. Mica tends to break over square corners. The break becomes dirty and carbon deposits occur, then a slight static surge is all that is needed to break down what insulation may remain and a ground to the frame results. When once started the voltage of a machine of this type is sufficient to hold the arc until the machine is destroyed. Therefore mica was not used in this job at all.

This machine had been connected in Delta at the factory but it was thought best to change the connection to Star and ground the neutral. Considerable argument was had with the engineers of the owners over the advisability of such a change. It was thought by some that the grounding of the neutral would result in transmission and distribution troubles. The final adoption of this scheme, however, has so far been very satisfactory. A few line disturbances due to leaky strain ball insulators were all that have occurred. It is the author's contention that with the neutral grounded the greatest difference of potential that can be developed between the line and the ground is thirty-eight hundred volts while with the delta connection and no grounding it is easily possible to get the full voltage of the generator. Also that any lightning surges which do come in past the very complete set of arresters provided will go to the ground by way of the grounded neutral instead of through the insulation. Transformer tests have indicated that such will be the case.

It is a matter of regret with the author that there have been no heavy electrical storms since the repairing of this machine. The disturbances that have occurred have been light but the machine has gone through them with no bad effects. Heavier loads have been handled than were previously thought possible, the load running as high as twenty-two hundred and fifty kilo watts at times.

Reliability was the principal thing desired by the owners and it is thought that reliability has been secured. The final test of this machine cannot be made, however, until next summer when the electric storms so common in this locality occur. Transformer tests, however, both at the time the job was completed and since have upheld the author's contentions and the owners are very well satisfied with the results achieved. The cost of the work was insignificant as compared to the cost of a new machine.

CONCLUSION

The three jobs of repairing and rebuilding described in the body of this thesis are typical of the ordinary run of work encountered in the electric repair business. The only thing done which was perhaps out of the ordinary was the rebuidling of the rotor of the thirty-five horse power Fairbanks Morse & Co., motor. The manufacturers have assured the author that this particular piece of work had not been done before on any of their motors, it being the practise of the company to junk such rotors and supply new ones. They expressed considerable satisfaction that the work had been done so quickly and at so small expense.

It is often the case that considerable money must be risked on the judgement of the repair man. This was the case in the rebuilding of the stator of the fifteen hundred kilo volt ampere generator. The cost of both labor and material are constantly increasing and the man who tells an owner that by spending one thousand dollars on a machine certain desired results will be accomplished must know that his conclusions are right. It is not good practise to guarantee results. A guarantee is often a source of great trouble to both parties to the agreement. However, until the repair man has reached the point where his experience and training are such that reliance can be safely placed in his judgement he should not attempt to sell his opinions to others where any great amount of money might be involved .

The author made a very serious mistake of this nature a few years ago in laying out the power equipment in a large gold mill. The mistake was discovered in time so that no great amount of money was lost to the owners. It is needless to say, however, that this owner is not among the author's customers today. As is stated in the preface to this thesis reliability must be the factor on which the owner can always depend. Ordinarily one instance in which it was not given is enough to cost the repair man a great amount of work which he might otherwise have had.

The demands made on Engineers are much more exacting than those made on members of other professions. The mistakes that Engineers make, though the causes may have been ever so hard to determine beforehand, are very easily seen after the machine has burned up or the bridge has fallen down and such mistakes are never forgiven. It therefore behooves the man who would sell his opinions on electrical machinery to others to know his subject well. An armature winder with no college education can often tell the college graduate in engineering much about the actual operation of motors and generators. All knowledge gained is valuable no matter from what source it is acquired.

BIBLIOGRAPHY

For a bibliography of this thesis the author can only say that all of the results are from his own experience and observation. There are very few books that to his knowledge deal with this particular branch of the work.

In connection with the first machine described in the body of this thesis some correspondence was had with Fairbanks Morse & Co. Most of it had to do with the method employed by that company in making the cast bronze short circuiting ring and practically all of it came to hand after the completion of the work. In the case of the last machine described several conversations were had with the engineers of The Federal Light and Traction Co., and with Mr. Burnell R. Ford, Electrical Engineer.

It is the author's experience that the repair man must almost always proceed on his own initiative. In completely rebuilding a machine as was done in the case of the second machine in this article it is often a very slow and difficult task to secure advice or data from the manufacturers. Some manufacturers hold that their data is for their own confidential use and will not send out such information. This was the case with the 100 horse power motor described in another place in this thesis.

A further bibliography is therefore impossible.

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